CHEMICAL CHANGES IN CARROTS DURING GROWTH

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(WITH FIVE FIGURES)

Introduction

This study was carried out in connection with a general investigation of the factors influencing quality in carrots. It was recognized that age and size of the roots play an important rôle in determining quality. Although it was realized that quality in vegetables, an indefinite term in itself, cannot be measured accurately, it was expected that the analysis for certain chemical constituents would give some indication of changes in eating quality as well as in nutritional value of the carrots.

Since it was necessary to take samples at various stages of the growth period, the plan of the experiment was enlarged so as to gain some information regarding the rate of growth of the plant, the rate at which certain mineral nutrients are absorbed, and various products of photosynthesis are formed.

Materials and methods

The carrots for this study were grown in the gardens of the Department of Vegetable Crops at Cornell University during the summer of 1932. Manure and a 5–10–5 fertilizer were applied to the soil prior to sowing. An overhead irrigation system supplied adequate moisture to the plants during periods of drought. Seed of the Chantenay variety was sown May 1 in rows 18 inches apart. About August 15 the carrots had attained the optimum size for market. Growth of the roots continued until the last day of sampling, October 15, but they were then of such a large size that they would have been considered of inferior quality on the market.

Sampling

The first sample was taken June 16, one and a half months after sowing of the seed. Between June 16 and August 15 the carrots were sampled at approximately semi-monthly intervals; after August 15 at monthly intervals. A representative sample of at least twenty individual plants was taken at noon of each sampling day and an aliquot of the composite sample was later used for chemical analysis. The whole plant with the exception of the smaller side roots was pulled and taken at once to the laboratory. Roots and tops were separated and the weight of each was recorded. The material from both lots was then cut into small pieces and mixed thoroughly. An aliquot of 100 gm. was used for the determination of dry weight while another aliquot of 150 gm. was dropped into jars containing sufficient 95 per cent. alcohol to make a final concentration of about 75 per cent. After boiling for 10 minutes the jars were sealed and stored for analysis.

Methods of chemical analysis

(a) Dry weight.—The material was dried in a ventilated oven at 60° C. for 40 hours after the sample had been heated at 100° for one hour to inactivate the enzymes.

(b) Sugars.—A modification of the picric acid reduction method described by Willaman and Davison (**8**) was used.

(c) Starch.—The extracted material was digested with takadiastase at 38° C. for 20 hours, filtered, and the filtrate clarified with lead acetate, deleaded, and hydrolyzed with dilute hydrochloric acid. Glucose was determined in the hydrolyzed material by the picric reduction method.

(d) Crude fiber.—A slightly modified official procedure was used.

(e) Lignin.—A method which was described in detail by Phillips (**6**) was used. Lignin was determined gravimetrically after cellulose had been removed by fuming hydrochloric acid. Corrections were made for ash and protein.

(f) Calcium and phosphorus.—These constituents were determined by the official method recommended by the A.O.A.C. (**5**).

Analytical results

The results of the chemical analyses were expressed as percentages of dry weight, which made it possible to eliminate certain fluctuations in composition caused by variations in the moisture content of the plant. In order to study the relationship between the rate of formation of the various chem-

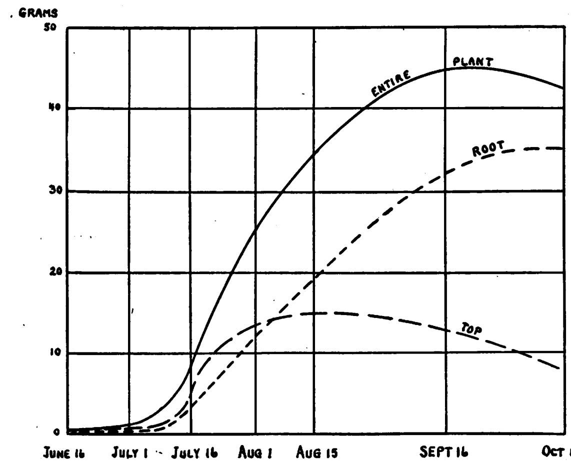

Fig. 1. Rate of growth of entire carrot plant, root, and top in grams of dry weight.

ical constituents analyzed, the data were also calculated as weight per plant or root respectively. A graphic representation of the rate of growth of the root, top, and entire plant is given in figure 1. The various curves do not give a clear conception of the true relative growth rate; a better representation can be obtained when the rate of growth is plotted on a ratio scale (fig. 2), where the paper in the vertical direction is ruled on a logarithmic

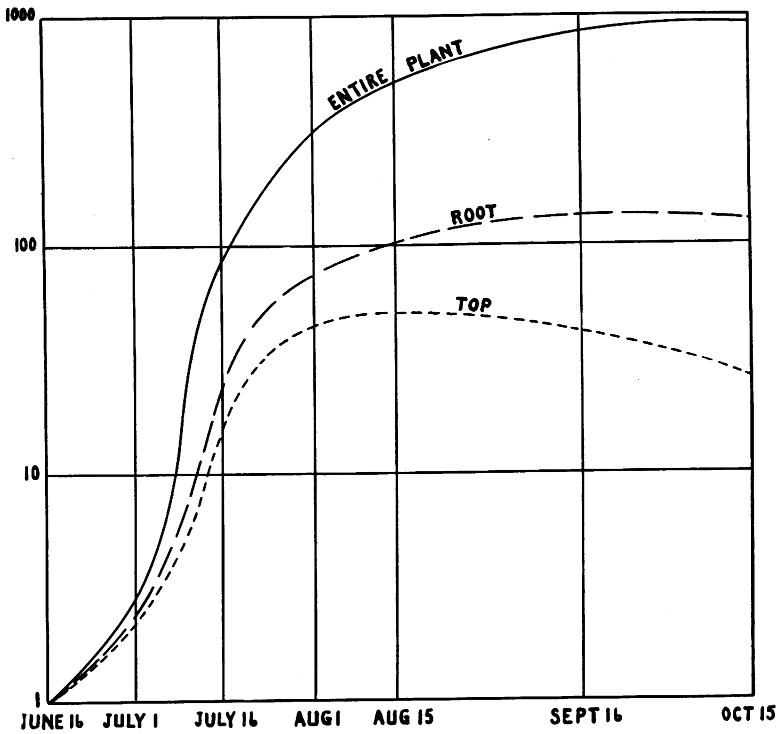

Fig. 2. Rate of growth of entire carrot plant, root, and top. Data (calculated on dry weight basis) are the same as given in fig. 1, but are plotted on the ratio scale.

scale while the horizontal scale gives time in absolute amounts. The nature of the ratio scale is discussed in detail by CHADDOCK (2). The spacings in the vertical direction represent true ratios, the slope of the curve indicates the rate of increase or decrease, and the slopes of different curves are comparable and represent comparative rates of increases or decreases regardless of the absolute values. Only the slopes are comparable, not the levels of the points above the base line. The obvious advantage of using such a scale is to bring several curves close together for comparison and to show the true relationship between relative increases or decreases. The ratio scale has been used by BUCHANAN and FULMER (1) to illustrate the growth rate of bacteria. Strangely enough, few other workers dealing with growth rates of plants have used this method of presentation.

A few striking facts become apparent when the chemical composition of the root at the various stages of growth is examined with regard to those constituents which ordinarily are considered as factors determining quality.

The moisture content fluctuated somewhat and decreased slightly with age. The decrease in the water content was not more than 2.5 per cent. of the entire fresh weight, however, and with an average moisture content of nearly 90 per cent. it becomes doubtful whether such small fluctuations can materially influence the crispness of the tissue as far as eating quality is concerned.

The total sugar content increased slowly, and on the dry weight basis was about 2.5 per cent. higher in the old carrots than in the young ones (table I and fig. 3). A very definite relation was found between reducing

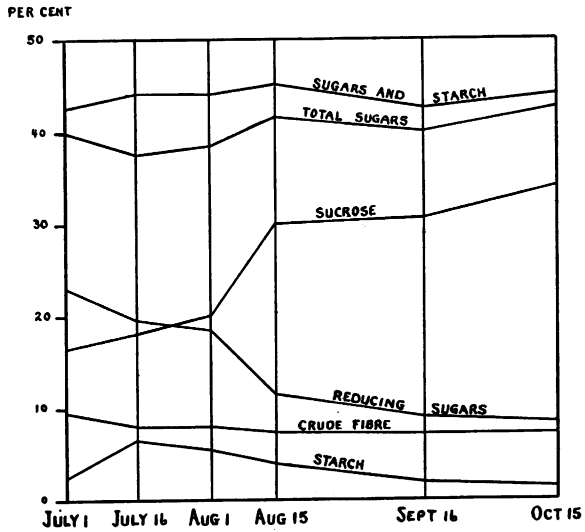

FIG. 3. Chemical composition of carrots at various stages of the growth period. Data expressed as percentages of dry weight.

sugars and sucrose. While the reducing sugars declined steadily, sucrose increased at about the same rate. On a percentage basis reducing sugars dropped to less than one-half of their original value while the percentage of sucrose more than doubled. In order to determine the relative sweetness of carrots at different stages of age it is important to identify the reducing sugars present, since different sugars vary widely in their relative sweetening power. For instance, should the greater part of the reducing sugars be in the form of fructose, young carrots would be sweeter than old ones. On the other hand, if glucose forms most of the reducing sugars the relation

TABLE I

CHEMICAL COMPOSITION OF CARROT ROOTS AND TOPS AT VARIOUS STAGES OF GROWTH. ALL DATA EXPRESSED ON DRY WEIGHT BASIS

DATE	DRY WEIGHT	AVERAGE WEIGHT OF PLANT	SOLUBLE NITROGEN	PROTEIN NITROGEN	TOTAL NITROGEN	REDUCING SUGARS	SUCROSE	TOTAL SUGARS	STARCH	CRUDE FIBER	LIGNIN	CaO	P_2O_5
ROOTS	%	gm.	%	%	%	%	%	%	%	%	%	%	%
June 16 ...	10.04	0.037											
July 1	11.34	0.1066	0.580	1.234	1.814	23.24	16.53	39.77	2.52	9.50	2.98	0.066	1.356
July 16 ...	12.42	3.116	0.436	0.914	1.350	19.32	18.20	37.52	6.62	7.94	2.81	0.094	0.919
Aug. 1	11.12	11.70	0.612	0.803	1.415	18.52	20.05	38.57	5.47	7.83	2.95	0.078	0.933
Aug. 15 ...	11.38	19.17	0.481	0.861	1.342	11.53	29.82	41.35	3.89	7.63	2.49	0.080	1.004
Sept. 16 ...	12.50	32.11	0.674	0.786	1.460	9.86	30.36	40.22	2.05	7.24	1.83	0.069	1.121
Oct. 15 ...	12.44	34.82	0.621	0.766	1.387	8.46	33.91	42.37	1.48	7.30	1.95	0.061	1.031
TOPS													
June 16 ...	14.17	0.2996											
July 1	16.53	0.6771	0.471	0.309	0.780	2.81	5.34	8.15	0	9.04	5.18	3.37	1.158
July 16 ...	16.13	4.655	0.286	0.261	0.547	6.57	1.48	8.05	0	10.60	6.82	3.36	0.664
Aug. 1 ...	16.95	13.57	0.233	0.189	0.412	7.91	1.99	9.90	0	11.03	6.50	3.23	0.778
Aug. 15 ...	17.62	15.14	0.174	0.198	0.372	6.87	1.52	8.39	0	10.47	8.13	3.59	0.724
Sept. 16 ...	19.39	13.04	0.158	0.224	0.382	3.12	1.70	4.82	0	12.24	11.21	4.93	0.683
Oct. 15 ...	21.96	7.879	0.170	0.208	0.378	2.70	1.53	4.23	0	13.44	10.73	4.57	0.673

would be reversed. The isolation and identification of certain sugars in a mixture is a difficult procedure. PINOFF and GUDE (7) describe a color test using ammonium molybdate, which is fairly specific for fructose. Using this test, only traces of fructose could be found in the mixture of sugars extracted from young carrot roots. Assuming that all reducing sugar is present as glucose, older carrots should be 19 per cent. sweeter than young ones when the relative amounts of these sugars present is considered. This agrees very well with the fact that old carrots were found to be noticeably sweeter to taste than young roots. This fact conforms with the statement of HASSELBRING (3) who considers the natural content of sucrose as determining largely the flavor in carrots.

The percentage of starch increased very rapidly at first to 6.6 per cent., then declined slowly to 1.5 per cent. of the dry weight.

Very surprising is the fact that the amount of crude fiber, which was expected to increase with age, actually declined. The same holds true for lignin, which occurs in small amounts particularly around the tracheae.

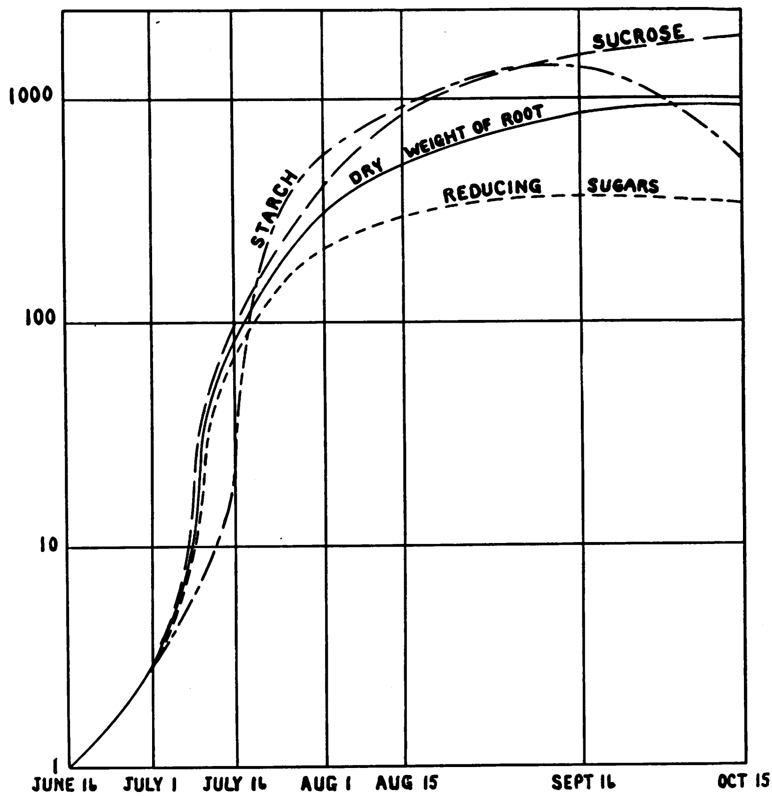

FIG. 4. Rate of accumulation of carbohydrates in carrot roots. Data plotted on ratio scale.

When the growth curves for the roots and tops are considered separately it is found that their rates of growth differ widely (fig. 2). While the tops had ceased growing entirely August 15, the roots were still gaining in weight two months later. The tops actually lost some of their dry matter after August 15. This loss was partly due to respiration and the slow dying off of the outer leaves. It can safely be assumed, however, that the principal loss was due to translocation of sugars from the leaves to the roots. In this connection it is interesting to notice that no trace of starch was found in the leaves at any time.

Figure 4 shows that reducing sugars accumulated in the roots at a much slower rate than sucrose, which necessarily resulted in a much lower percentage of glucose than sucrose at the end of the storage period. The formation of starch in the roots was most rapid during July, the relative rate of increase being greater than that of the total dry weight or of the sucrose content in the roots in this period. During the last month, from September 15 to October 15, there was a sharp drop in the starch content. Apparently, the starch was reconverted into sucrose, which continued to accumulate until the last day of sampling.

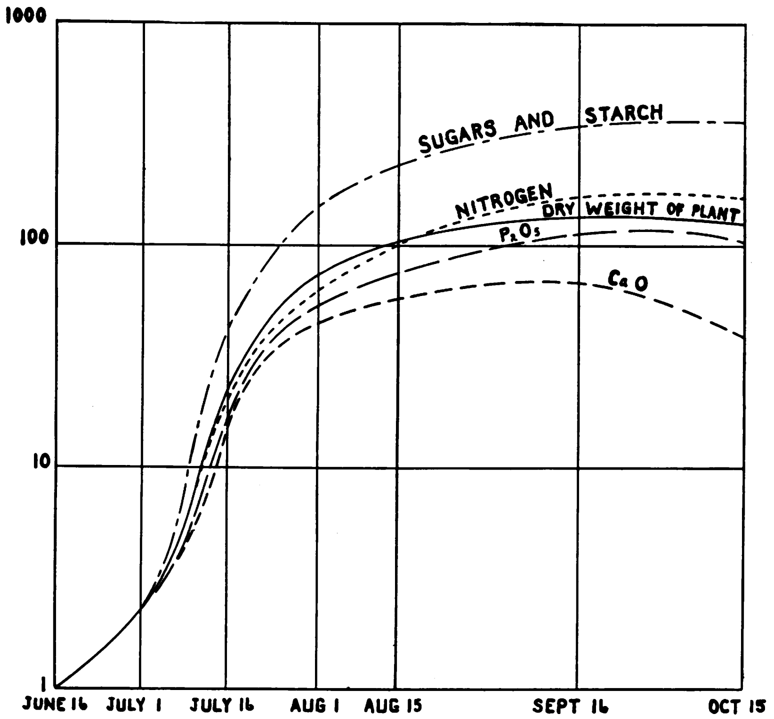

FIG. 5. Rate of absorption of calcium, phosphorus, and nitrogen and rate of accumulation of starch and sugars in the entire plant. Data plotted on ratio scale.

In figure 5 is shown the relative rate of the absorption of some mineral constituents, calcium, phosphorus, and nitrogen, by the entire plant. It is obvious that the relative rate of absorption of minerals is much greater at the beginning of the growth period than at the end when compared with the accumulation of photosynthetic products. During the last stage some of the mineral and nitrogen constituents actually disappeared from the plant, probably through the dying off of the outer leaves. It is doubtful whether any minerals actually migrated out of the plant through the roots. The more rapid loss in calcium as compared with the loss in phosphorus or nitrogen is explained by the fact that the tops contained four to seven times as much calcium as the roots, while phosphorus and nitrogen were distributed more evenly through the entire plant.

Discussion

There is a general assumption among consumers that small young carrots are far superior to large old ones, which is reflected by the fact that young carrots bring a much higher price on the market. The present study makes it extremely doubtful whether this assumption is justified. The analytical data show clearly that sweetness in carrots, which probably is controlled primarily by their sucrose content, increases markedly with age.

In the present study no data were obtained which support the general idea that young carrots are more tender than old ones. On the contrary, the amount of crude fiber was found to decrease slightly with age. Several persons in the Department of Vegetable Crops, Cornell University, who compared young and old carrots with respect to tenderness, agreed that no significant difference could be observed between the two groups. If a slight difference was noticed it was always in favor of the old ones. Chemically and microscopically no change in the amount of lignified matter could be found. In older carrots, however, the cells of the outermost cortex are very much smaller, which brings the cell walls closer together and consequently the skin is slightly harder than in young carrots. Under certain conditions it may be found that young carrots are more crisp than old ones, especially if the latter group has been kept in storage for some time. Crispness is controlled by the water content of the roots and the turgidity of the cells.

The color of the carrots as determined by the amount of carotene present improved decidedly with age. Although no measurements of the relative amounts of carotene present were made, the difference in color was striking and consistent. Since it is a generally accepted theory that carotene and vitamin A content are closely connected, this would suggest the possibility that the vitamin A content in old carrots is higher than in young ones. The percentage of dry matter and combined sugars and starch was shown to increase slightly with age while the amount of crude fiber decreases. This indicates that the food value of carrots tends to increase rather than decrease with age.

HASSELBRING (3) concluded from his data that starch is absent in carrots, although he cited the work of other investigators who reported its presence. The writer was able to verify the occurrence of starch by identification of starch grains in the dried root tissue.

The curves obtained for the rate of growth and the rate of accumulation of photosynthetic products are extremely smooth, especially if it is realized that this experiment was carried out in the field under variable weather conditions.

The rôle which the root plays as a storage organ is well illustrated. For two months after the tops had ceased growing, translocation of carbohydrates from the tops to the roots continued.

Little work has been done on the rate at which mineral constituents are absorbed by vegetables. Such studies may be of importance in determining the proper time at which fertilizer can be applied to the plants to best advantage. KOTOWSKI (4) made such a study for several vegetables. However, he took only three samples during the entire growing period, and this can hardly be considered sufficient to give accurate data on the rate at which nutrients are absorbed. The present results show that all minerals had been absorbed by the plant at least a month before the roots obtained their maximum size.

Summary

1. Data are given which indicate that carrots lose neither in eating quality nor in food value as they grow older. The sucrose content, which is considered to determine flavor in carrots, rises decidedly while the percentage of crude fiber becomes slightly lower.

2. Older carrots are better colored owing to their higher carotene content.

3. The occurrence of small amounts of starch in carrot roots was verified. The tops were found to be free of starch throughout the growth period. Curves are presented of the growth rate of roots and tops and the rate of accumulation of various chemical constituents in the plant.

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